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ORIGINAL ARTICLE

Metabolic Responses to 4 Different Body Weight-Supported Locomotor Training Approaches in Persons With Incomplete Spinal Cord Injury

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Abstract

Objective: To describe metabolic responses accompanying 4 different locomotor training (LT) approaches.

Design: Single-blind, randomized controlled trial.

Setting: Rehabilitation research laboratory, academic medical center.

Participants: Individuals (N=62) with minimal walking function due to chronic motor-incomplete spinal cord injury.

Intervention: Participants trained 5 days/week for 12 weeks. Groups were treadmill-based LT with manual assistance (TM), transcutaneous electrical stimulation (TS), and a driven gait orthosis (DGO) and overground (OG) LT with electrical stimulation.

Main Outcome Measures: Oxygen uptake ($\dot{V}O_2$), walking velocity and economy, and substrate utilization during subject-selected "slow," "moderate," and "maximal" walking speeds.

Results: $\dot{V}O_2$ did not increase from pretraining to posttraining for DGO (.00±.18L/min, P=.923). Increases in the other groups depended on walking speed, ranging from .01±.18m/s (P=.860) for TM (slow speed) to .20±.29m/s (P=.017) for TS (maximal speed). All groups increased velocity but to varying degrees (DGO, .01±.18Ln[m/s], P=.829; TM, .07±.29Ln[m/s], P=.371; TS, .33±.45Ln[m/s], P=.013; OG, .52±.61Ln[m/s], P=.007). Changes in walking economy were marginal for DGO and TM (.01±.20Ln[L/m], P=.926, and .00±.42Ln[L/m], P=.981) but significant for TS and OG (.26±.33Ln[L/m], P=.014, and .44±.62Ln[L/m], P=.025). Many participants reached respiratory exchange ratios ≥1 at any speed, rendering it impossible to statistically discern differences in substrate utilization. However, after training, fewer participants reached this ceiling for each speed (slow: 9 vs 6, n=32; moderate: 12 vs 8, n=29; and maximal 15 vs 13, n=28).

Conclusions: DGO and TM walking training was less effective in increasing $\dot{V}O_2$ and velocity across participant-selected walking speeds, while TS and OG training was more effective in improving these parameters and also walking economy. Therefore, the latter 2 approaches hold greater promise for improving clinically relevant outcomes such as enhanced endurance, functionality, or in-home/community ambulation.

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An estimated 12,000 individuals in the United States sustain spinal cord injuries (SCIs) each year.[1] While these injuries typically forecast global challenges to function and health, improved methods of field stabilization, prompt acute medical intervention, and aggressive rehabilitation have been credited with permitting an increased proportion of the population to recover at least some measure of their preinjury motor function.[2] This preserved function can then be nurtured through various strategies to provide the best attainable function, personal independence, and well-being.

Throughout the past several decades, various body weight—supported treadmill-based and overground (OG) locomotor training (LT) approaches (LTAs) have been adopted and refined to more aggressively pursue the goal of enhanced postinjury function, which

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has led to their expanded testing and use in persons with motor-incomplete SCI. Stepping during LT is initiated or assisted using a variety of techniques, including manual assistance on a treadmill (TM), mechanical control by a driven gait orthosis (DGO), and transcutaneous electrical stimulation (TS). A variety of factors are known to influence the central and peripheral contributions to locomotor function, and these may offer insights regarding optimal LTAs[3-11]; however, an optimal LT strategy for enhancing walking function in those with motor-incomplete SCI has yet to be established. To address this limitation, a recent study at our center examining differences in performance among various treadmill-based LT methods and OG training with TS observed overall improvements in both velocity and distance.[9] However, while treatment effects for walking velocity and distance gains were greatest with OG training, greater distance following OG LT was the sole outcome found to be statistically different from other LT modes.

Among the unanswered questions concerning LT is whether improvements in walking performance might be either explained or accompanied to some degree by metabolic changes such as enhanced oxygen uptake ($\dot{V}O_2$), improved walking economy, and optimized muscle substrate utilization. The former question remains open to speculation, because most research attention paid to LT benefits has focused on functional and neural plasticity, and less so the potential benefit provided by training-induced enhancements of the cardiopulmonary or metabolic systems.[12-14] The latter question is equally important, because most persons with SCI live their lives at the lowest end of the human fitness continuum, which borders on fitness thresholds needed to both perform daily activities and stave off secondary complications associated with prevalent cardioendocrine disease.

To date, several studies have reported varying degrees of metabolic response to different LT stepping approaches. LT has been reported to increase $\dot{V}O_2$ and heart rate up to 6-fold over resting levels, an acute intensity of work that is typically sufficient to improve cardiorespiratory fitness (CRF).[15-17] Jack et al[18] reported higher peak oxygen consumption (VO_{2peak}) during robotic-assisted treadmill activity than during arm crank ergometry and concluded that it was a highly effective conditioning stressor. Otherwise, while a passive robotic guidance stepping technique commonly used in LT produced lower metabolic expenditures than therapist-assisted TM walking,[19,20] this difference may be abolished when subjects are instructed to provide maximal effort under each of the training conditions.[21] Nonetheless, it has since been suggested that passive LT results in low work intensities that provide insufficient cardiometabolic stress to improve fitness.[13] To date, no study has directly compared more than 2 LTAs, and only 1 study has investigated chronic training effects imposed by different LT modes.[22] In the latter investigation, Alexeeva et al[22] compared sustained conditioning effects using body weight−supported LT on an OG track and on a treadmill, with each treatment performed for 1 hour/day, 3 days per week for 13 weeks. Despite significant improvements in participant strength, balance, and walking velocity/distance, results of this training also showed unchanged aerobic capacity when assessed by arm crank ergometry. However, use of upper-limb exercise testing to assess putative metabolic benefits of lower extremity training may underestimate tangible cardiopulmonary training benefits, leaving the question of LT benefits being addressed unanswered. It remains unclear whether there are metabolic changes associated with LT that are apparent during walking but that are not observed with arm crank ergometry.

In the present study, we therefore investigated whether oxygen consumption ($\dot{V}O_2$), walking economy, and substrate partitioning were differently affected by the 4 most commonly reported LTAs—TM, TS, OG, and DGO—during walking at 3 participant-selected walking speeds (ie, slow, moderate, and maximal). We hypothesized that all LTAs would increase participant-selected walking speed and $\dot{V}O_2$ as well as improve walking economy and increase reliance on fat oxidation during activity. We further hypothesized that DGO and TM would result in smaller training benefits related to metabolic responses and substrate utilization, as these approaches provide greater assistance to the walker, resulting in more passive locomotion.

List of abbreviations:

ANOVA	analysis of variance
CRF	cardiorespiratory fitness
DGO	driven gait orthosis
LT	locomotor training
LTA	locomotor training approach
MLI	motor level of injury
OG	overground
SCI	spinal cord injury
TM	manual assistance on a treadmill
TS	transcutaneous electrical stimulation
$\dot{V}O_2$	oxygen uptake
VO_{2peak}	peak oxygen consumption

Methods

This investigation was a component of a larger clinical trial, and details on subject selection and intervention protocols have been published elsewhere.[9] In brief, the study included individuals with an American Spinal Injury Association Impairment Scale classification of C or D, an injury at the T10 spinal level or higher, the ability to take at a minimum 1 step, and the ability to stand with no more than moderate assistance (ie, ≤50% effort) from another person. Criteria for exclusion were orthopedic problems, a history of cardiac condition, or evidence of hip pathology that could be aggravated by LT. Written and verbal informed consent was obtained from all participants in accordance with the protocol for study approval by the Human Subjects Research Office, Miller School of Medicine, University of Miami. Figure 1 shows a Consolidated Standards of Reporting Trials diagram showing participant screening, allocation, randomization, and progress.

Participants were stratified by American Spinal Injury Association Impairment Scale lower-extremity motor scores and randomized to 1 of 4 LTA groups: TM, TS (Digitimer DS7AH[a]), OG (WalkAide stimulator[b]), or DGO (Lokomat robotic gait orthosis[c]). Participants underwent training 5 days per week for 12 weeks.

Body mass was partially supported by a body harness and an overhead lift, which provided no more than 30% support (except for the first week of training). The body weight support lift provides a digital display of the amount of weight being supported by the lift. Subjects were weighed prior to participation, and the amount of support provided by the lift was maintained at <30% of the weight of each subject. This level of body mass support is associated with gait kinematics similar to unsupported walking.[23]

Stepping assistance provided by the investigators was specific to each training approach. For TM, participants were encouraged to voluntarily step to the extent possible in accordance with published guidelines.[24] For TS, a flexor reflex response was elicited by bilateral, electrical stimulation of the common peroneal nerves. Stimulation was manually triggered and timed to coincide with the onset of the swing phase of stepping. Pulse parameters were modified during